US 20040149342A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2004/0149342 A1

Troughton (43) Pub. Date: Aug. 5, 2004

(54) PAPERMAKER'S FORMING FABRIC

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(21) Appl. No.: **10/354,452**

(22) Filed: **Jan. 30, 2003**

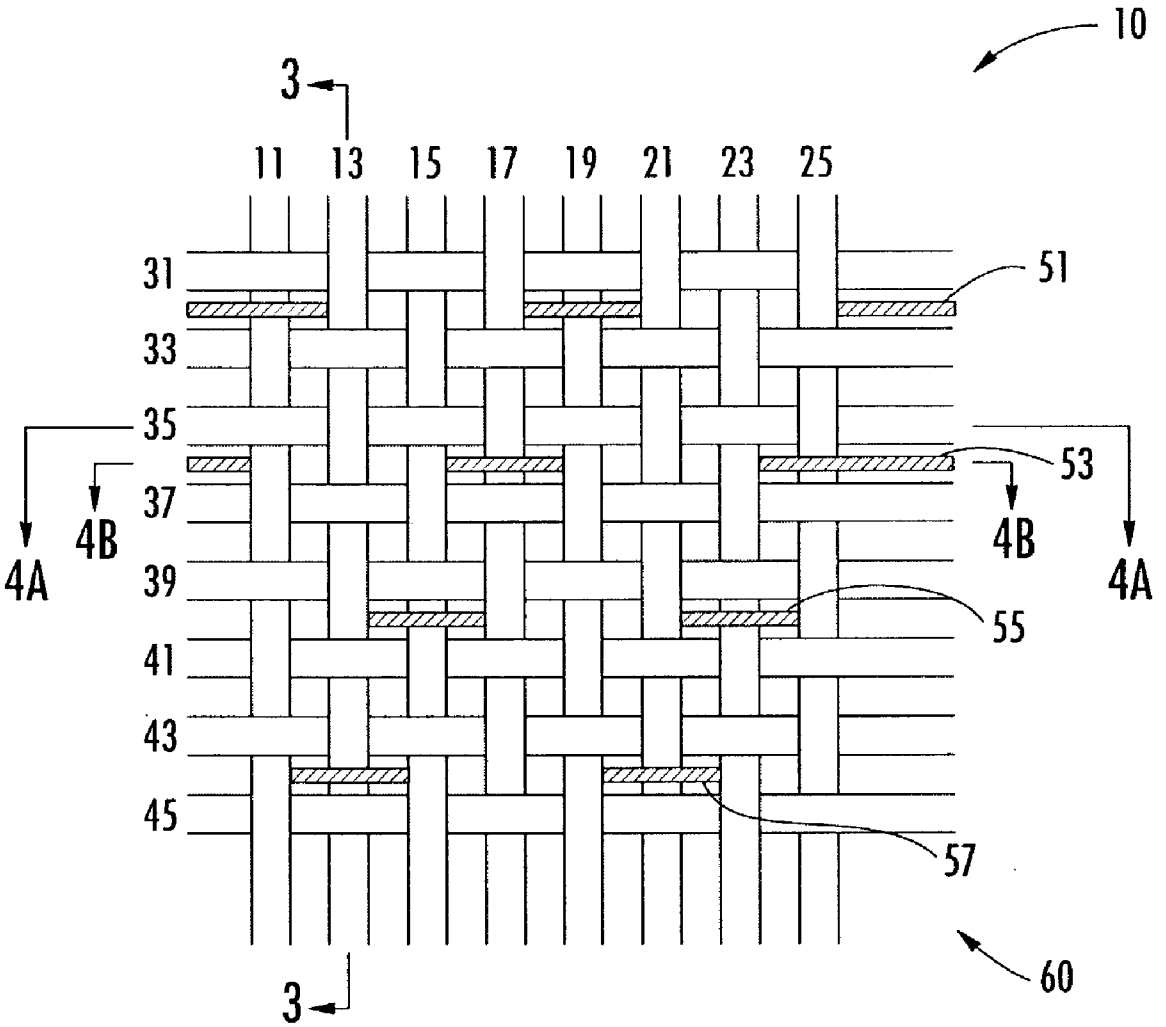
Publication Classification

(51) **Int. Cl.**[7] **D03D 25/00**; D21F 3/00; D03D 23/00

(52) **U.S. Cl.** ..... **139/383 R**; 162/358.2

(57) **ABSTRACT**

A papermaker's fabric includes top MD yarns, top CMD yarns, bottom MD yarns, bottom CMD yarns and stitching yarns. The fabric is formed in a plurality of repeating units, each of the repeating units including a set of top MD yarns, a set of top CMD yarns interwoven with the set of top MD yarns to form a top fabric layer, a set of four or eight bottom MD yarns, a set of bottom CMD yarns interwoven with the set of four or eight bottom MD yarns to form a bottom fabric layer and a set of stitching yarns interwoven with the top and bottom fabric layers. The bottom MD yarns and the bottom CMD yarns are interwoven in a series of repeat units in which each of the bottom MD yarns passes below two nonadjacent bottom CMD yarns to form bottom machine direction knuckles, each bottom machine direction knuckle being separated from one adjacent knuckle formed by that bottom machine direction yarn by two bottom CMD yarns and separated from another adjacent knuckle by four CMD yarns.



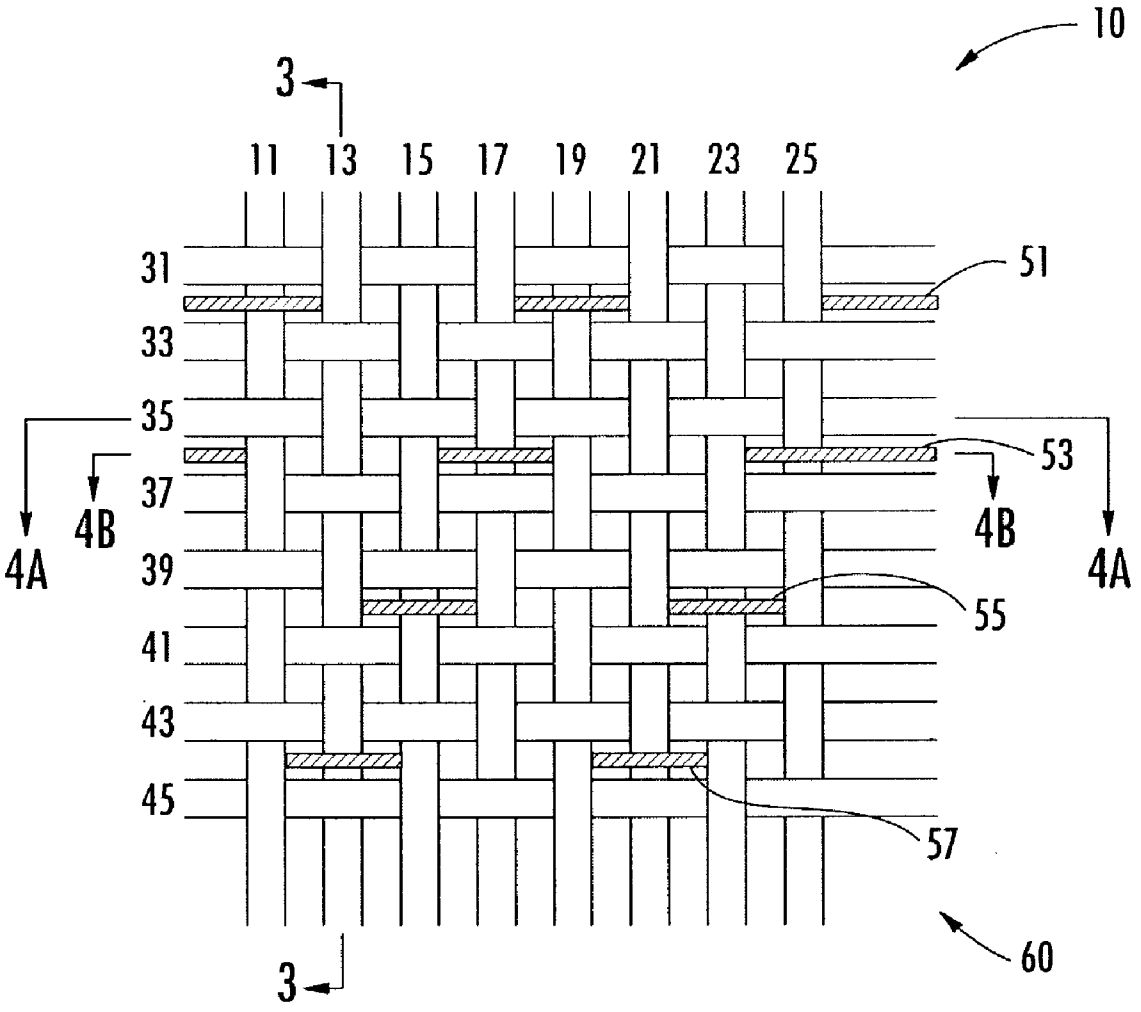

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FIG. 1.

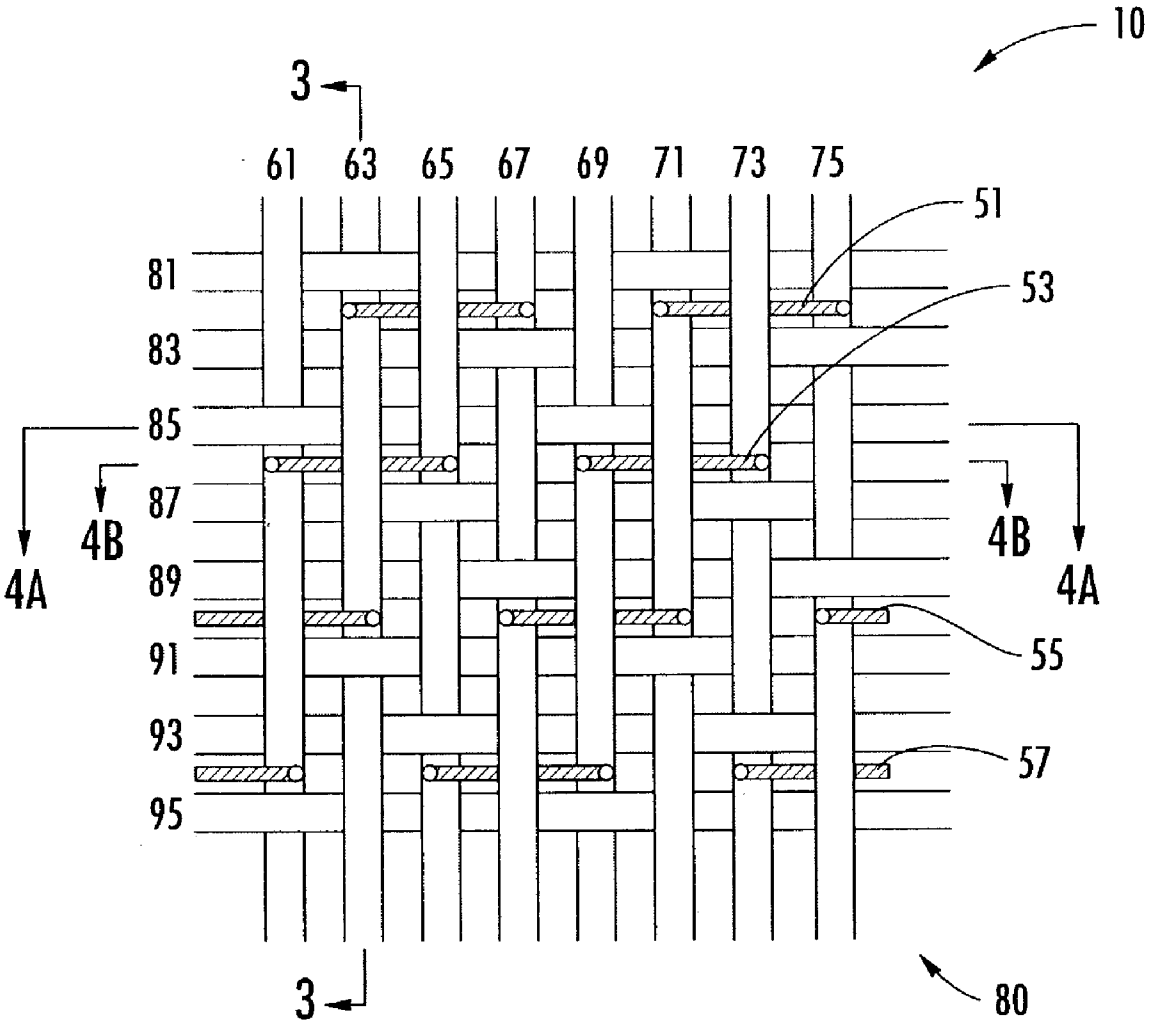
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FIG. 2.

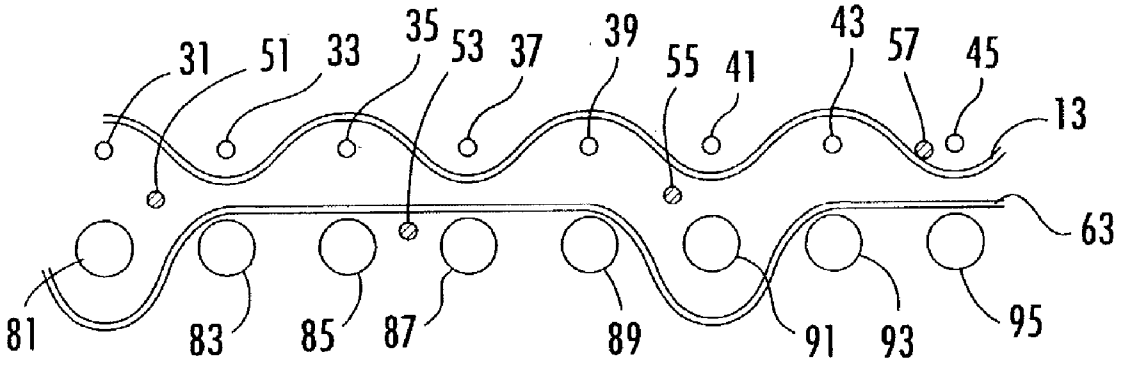

FIG. 3.

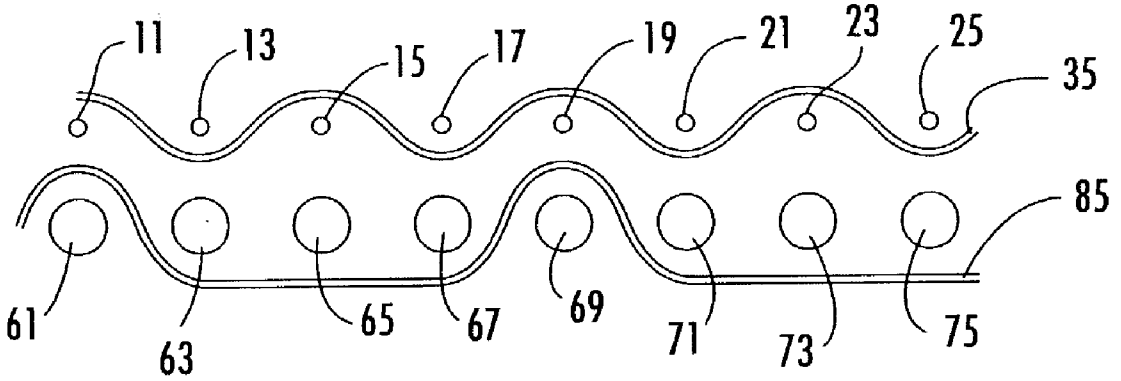

FIG. 4A.

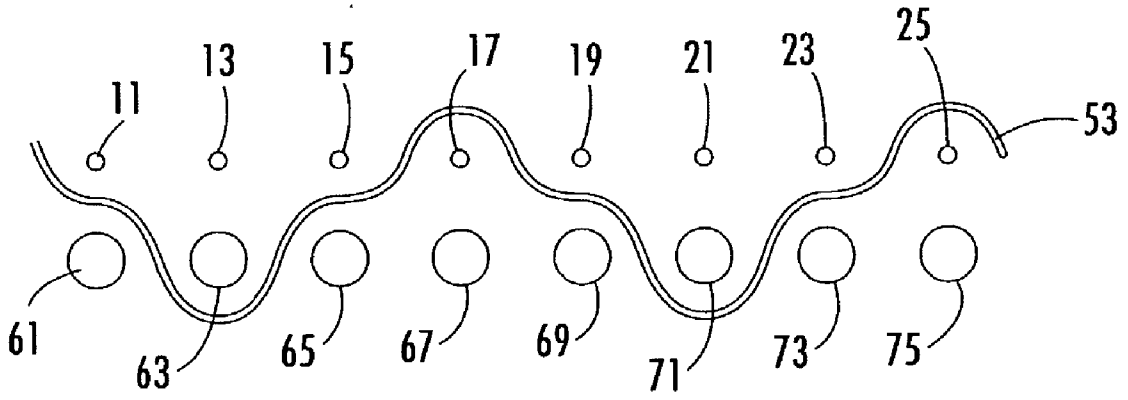

FIG. 4B.

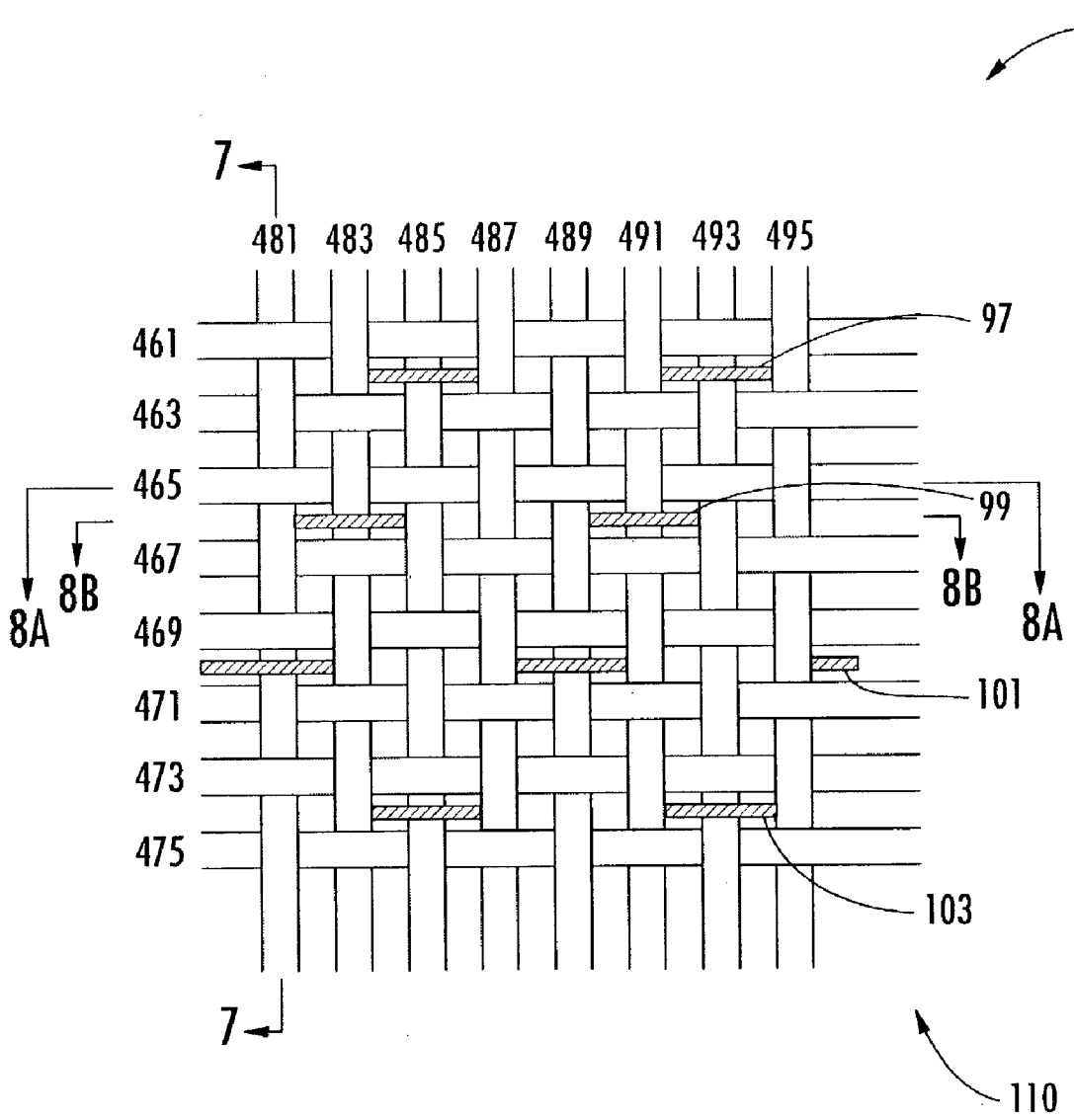
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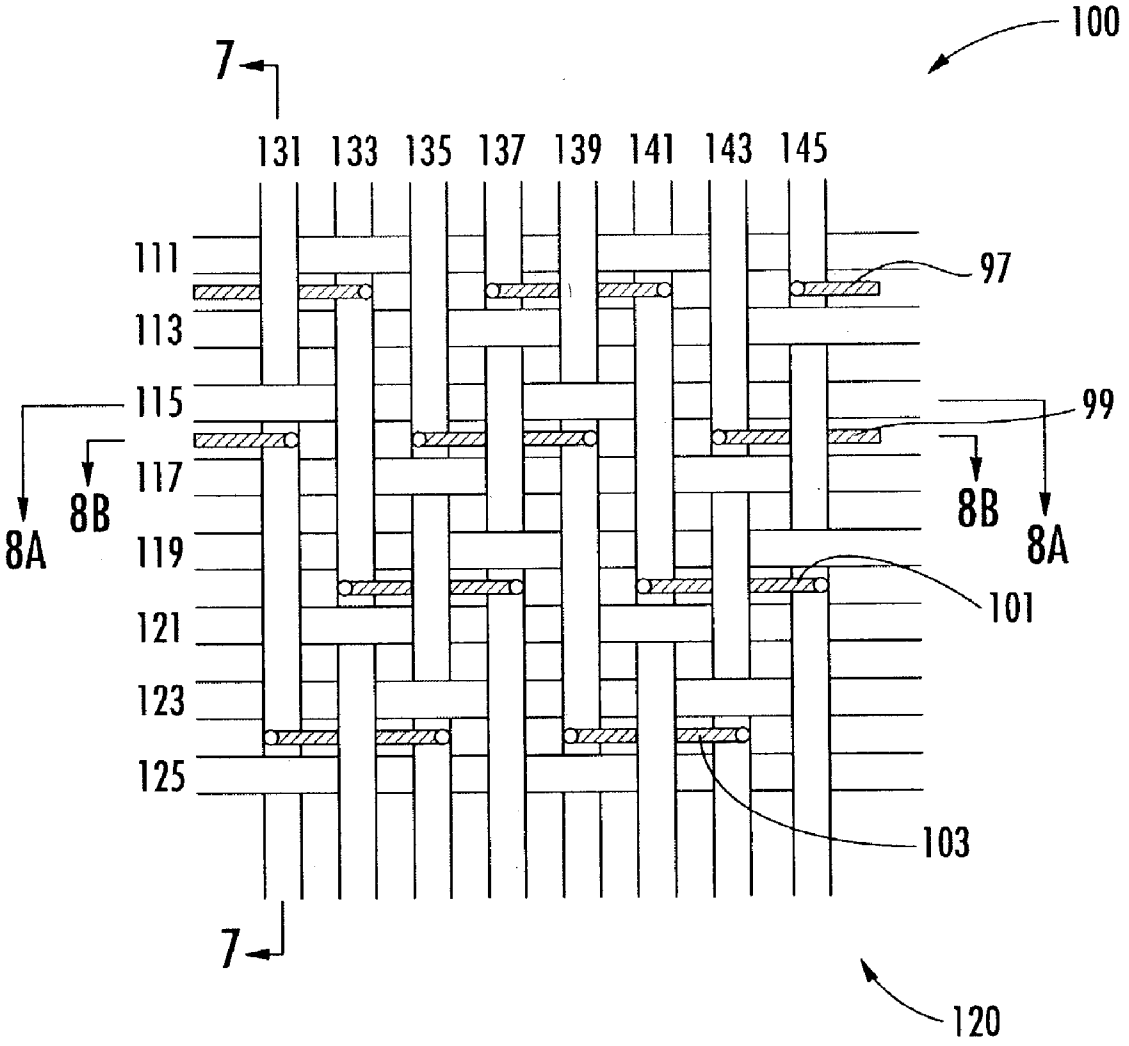
FIG. 5.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8A
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FIG. 6.

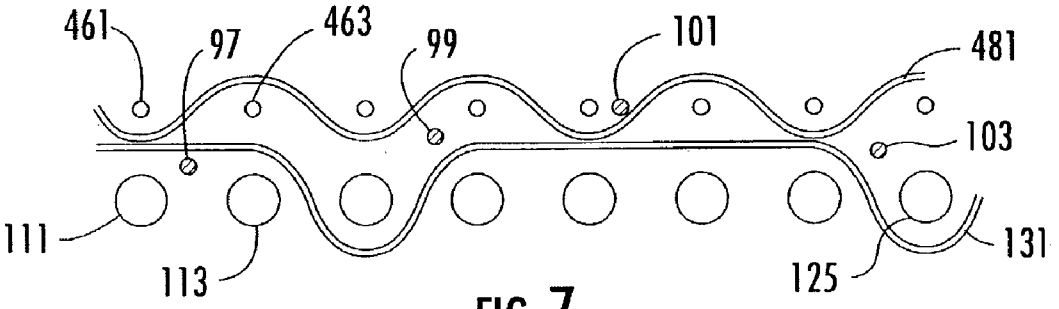


FIG. 7.

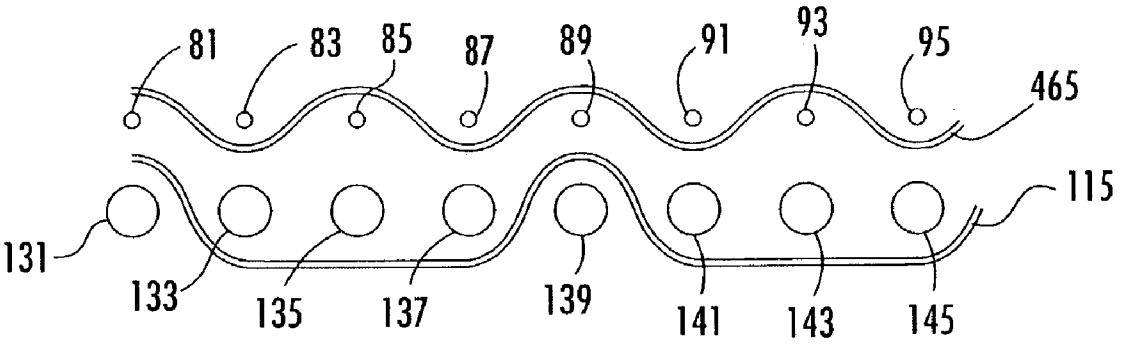


FIG. 8A.

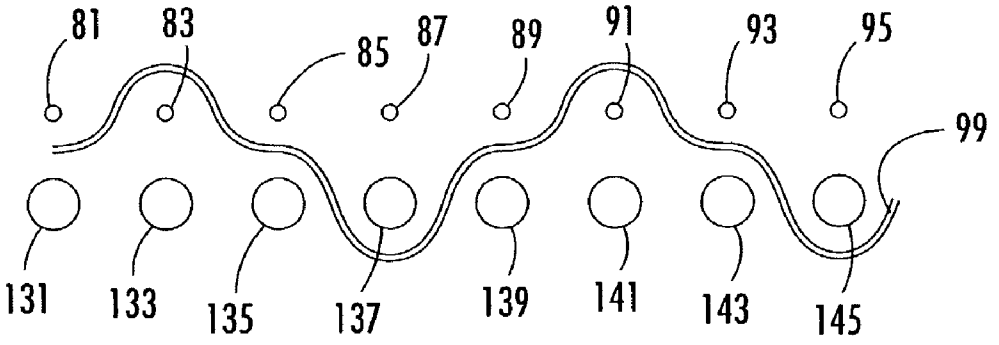
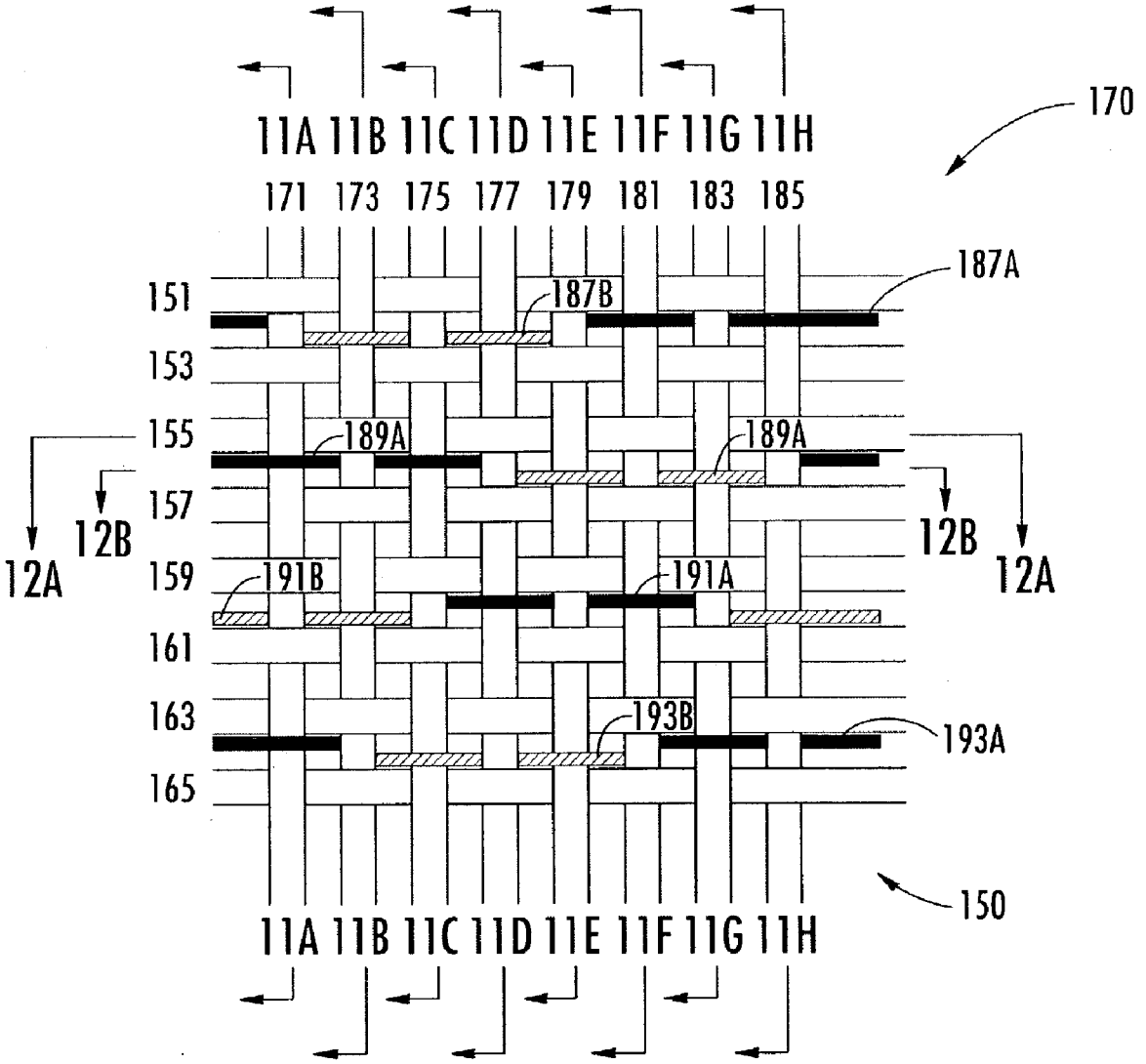


FIG. 8B.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187A
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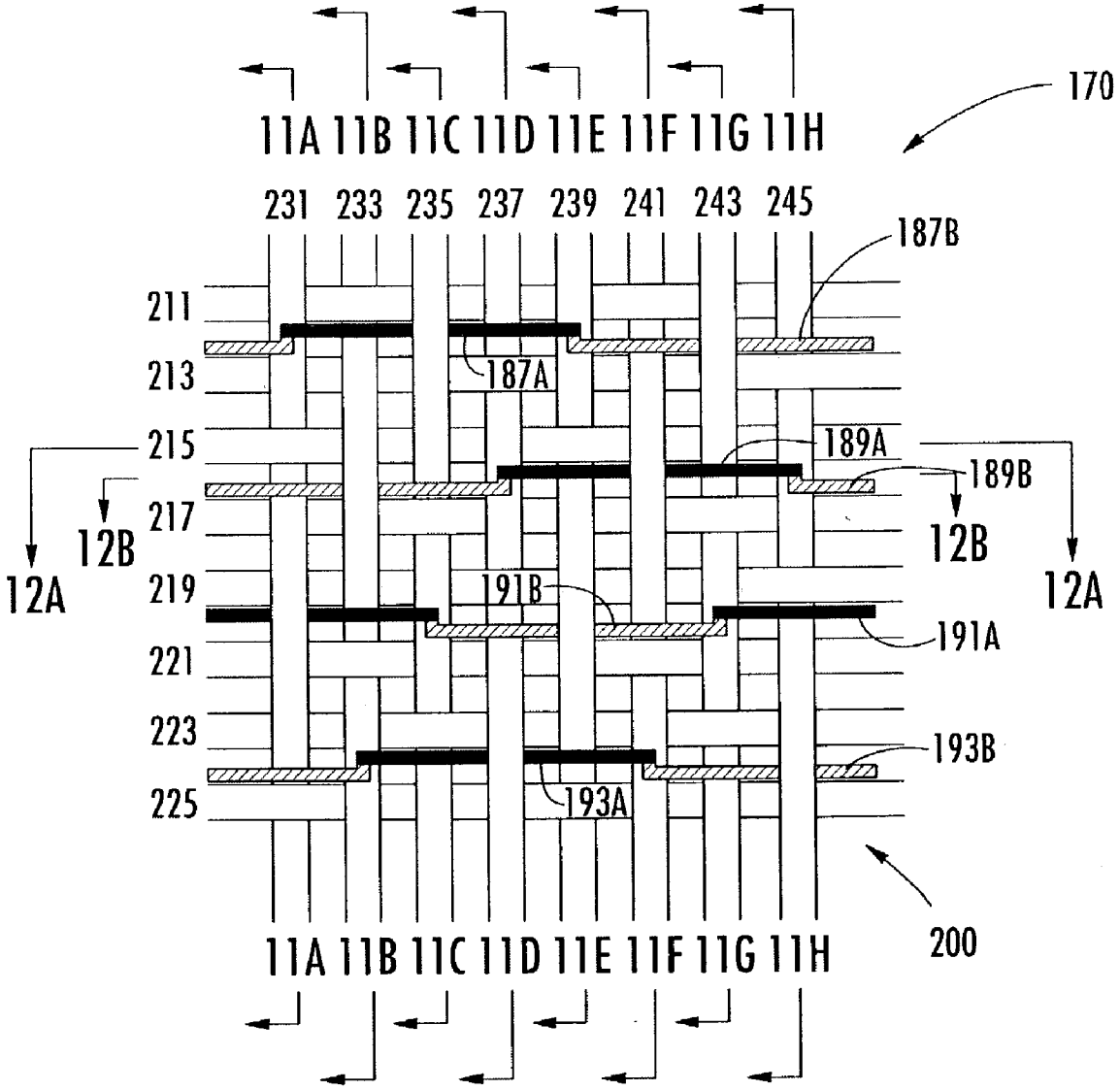
11A 11B 11C 11D 11E 11F 11G 11H

FIG. 9.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11A 11B 11C 11D 11E 11F 11G 11H
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FIG. 10.

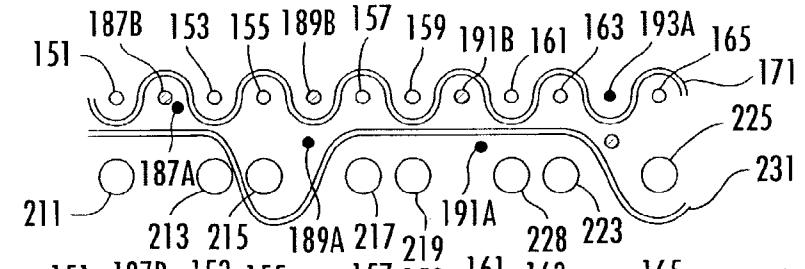


FIG. 11A.

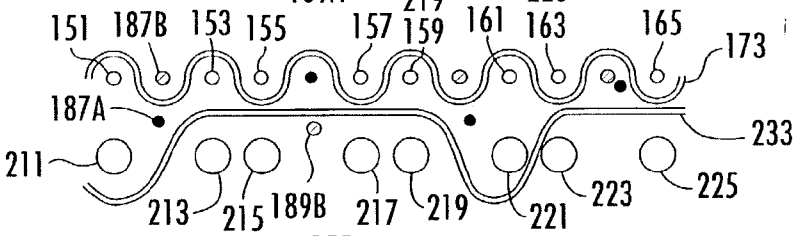


FIG. 11B.

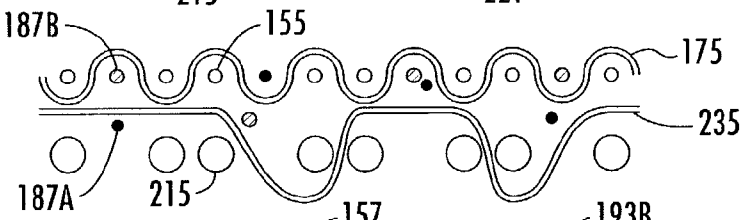


FIG. 11C.

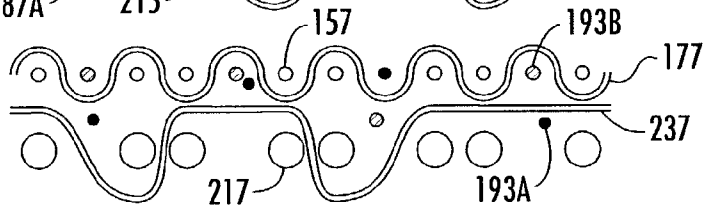


FIG. 11D.

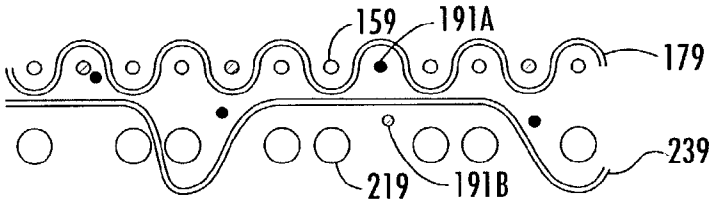


FIG. 11E.

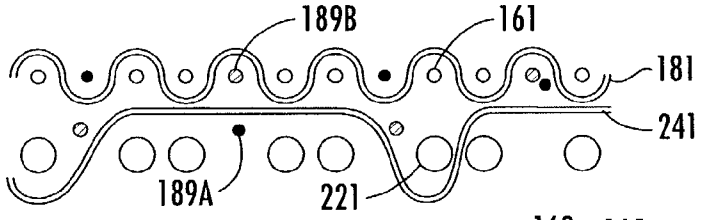


FIG. 11F.

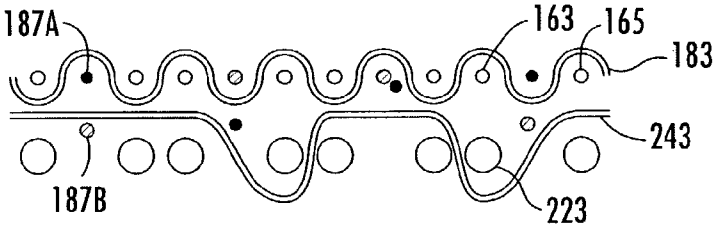


FIG. 11G.

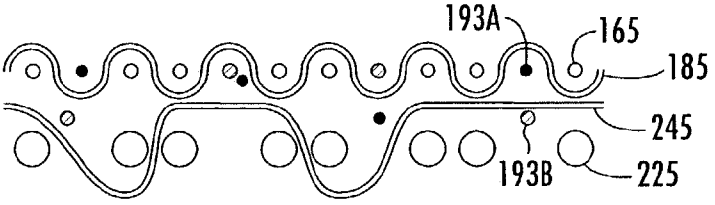


FIG. 11H.

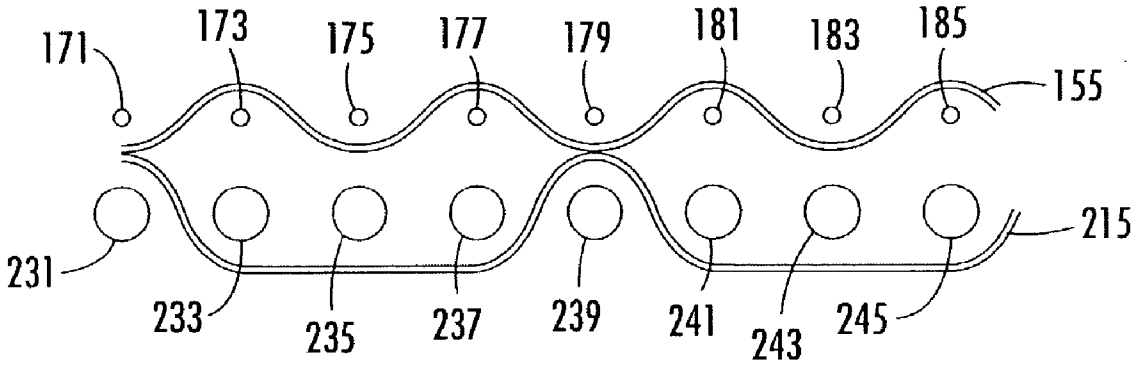


FIG. 12A.

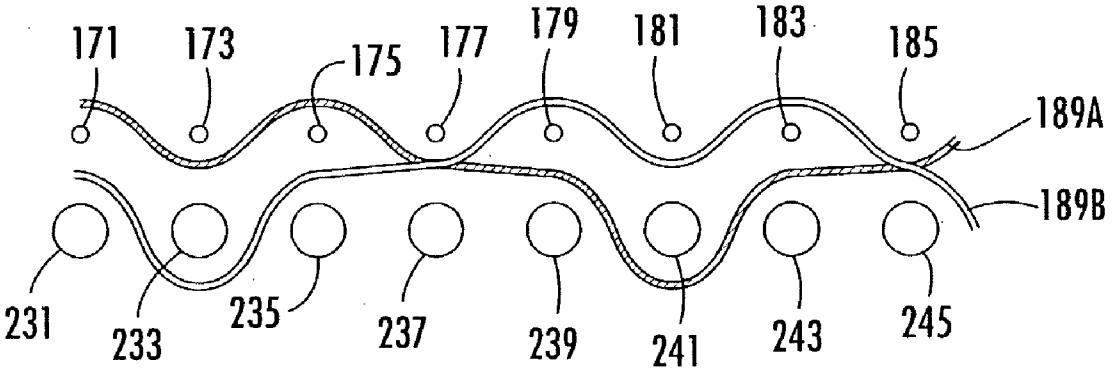
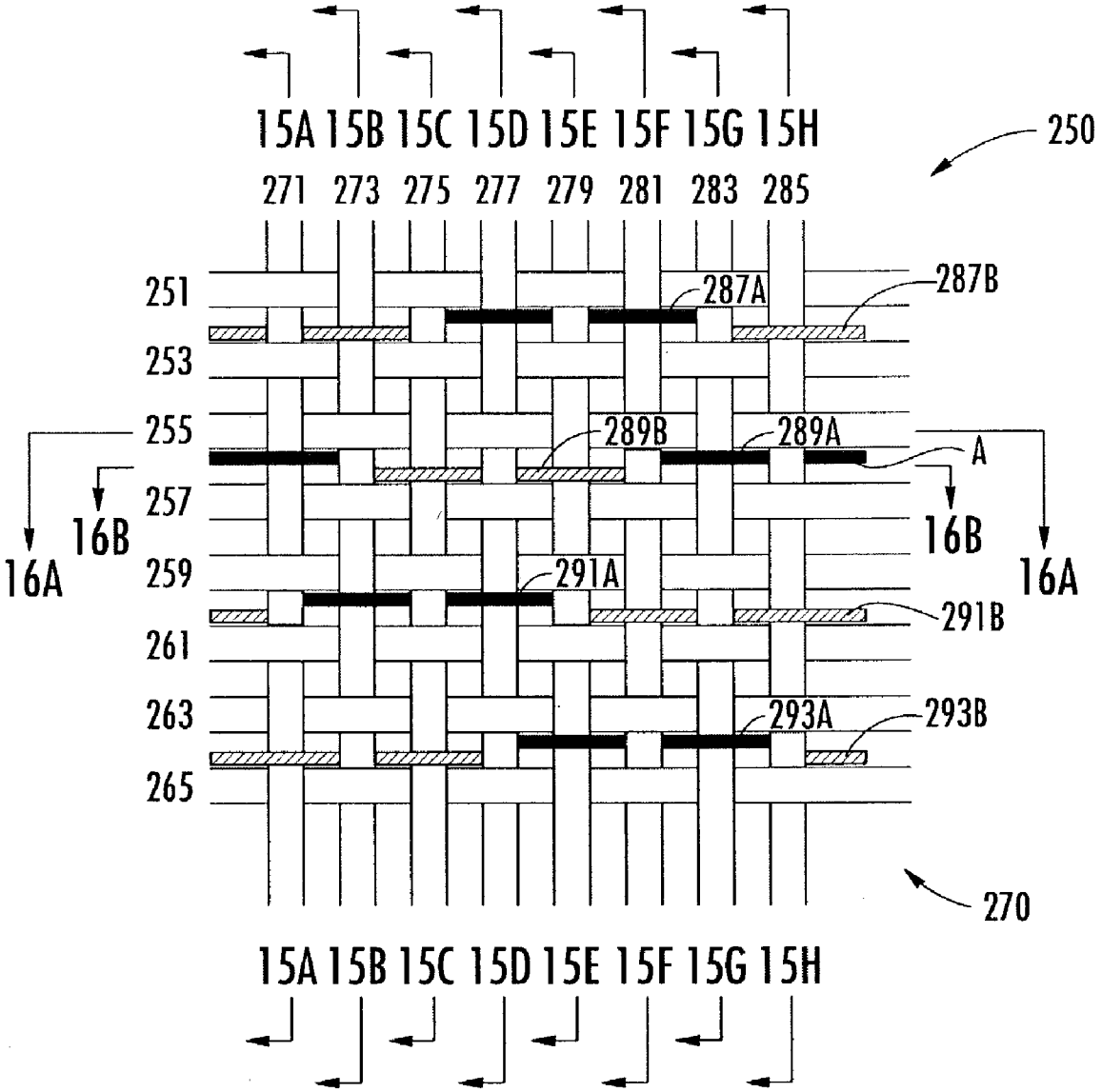


FIG. 12B.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15A 15B 15C 15D 15E 15F 15G 15H

FIG. 13.

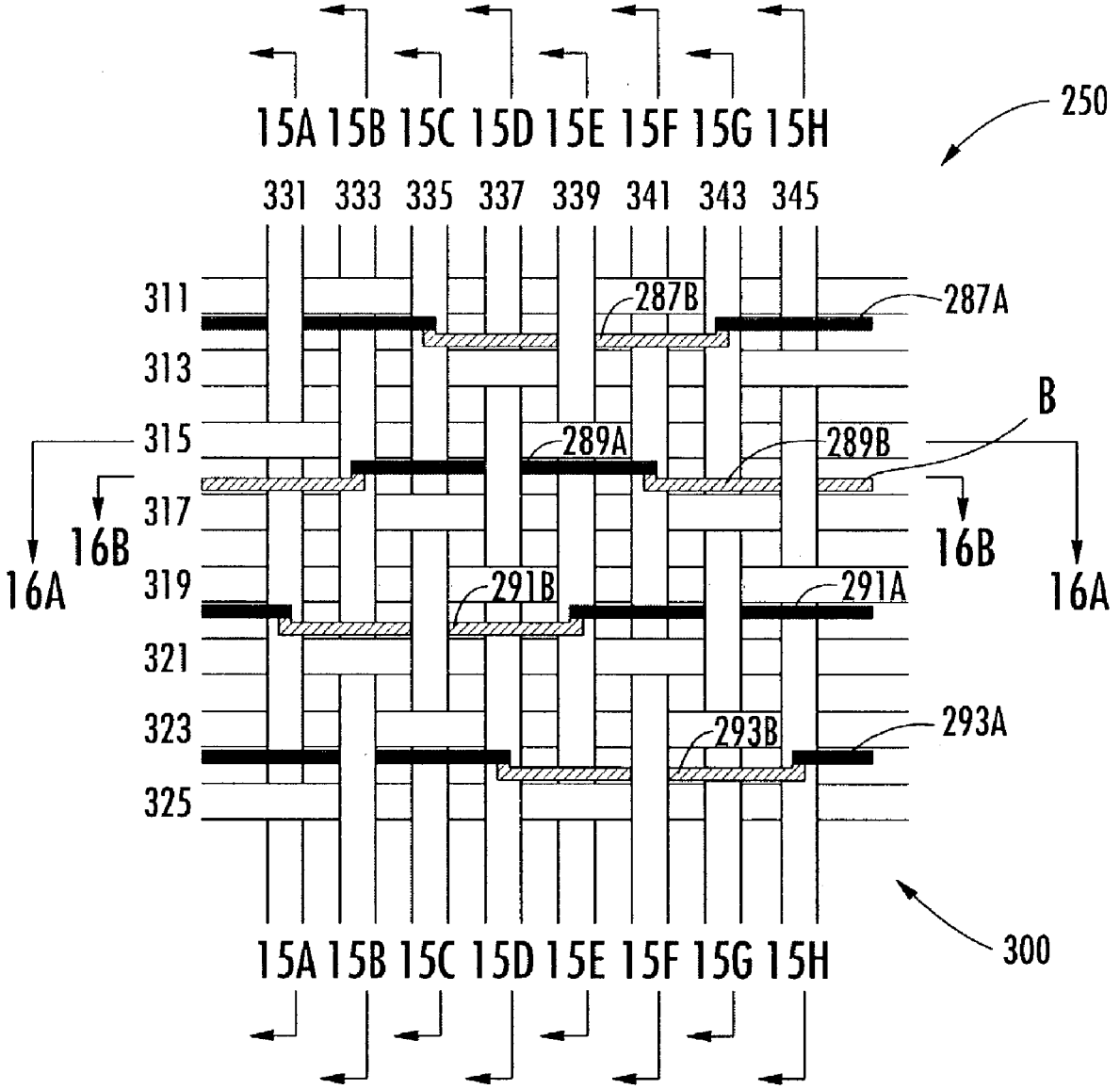
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FIG. 14.

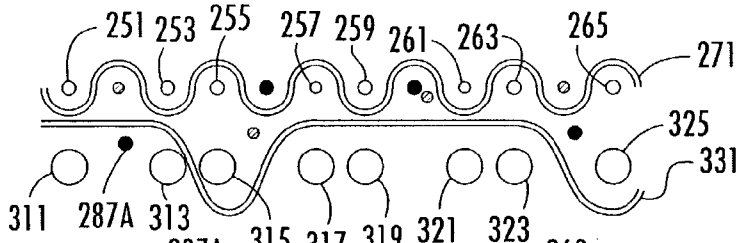

FIG. 15A.

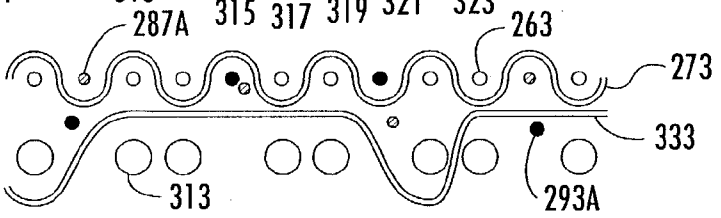

FIG. 15B

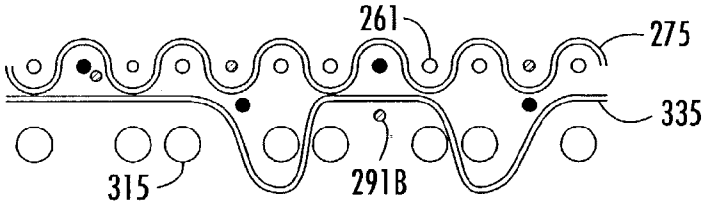

FIG. 15C.

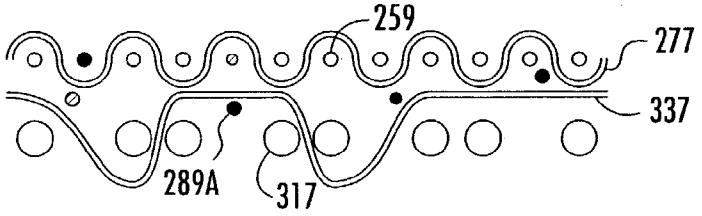

FIG. 15D.

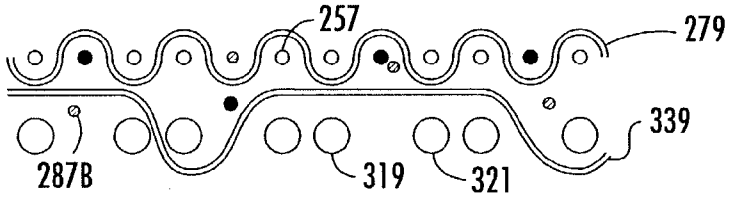

FIG. 15E.

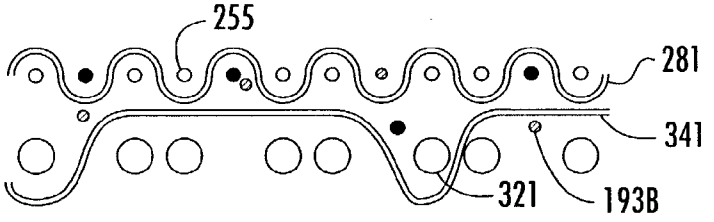

FIG. 15F.

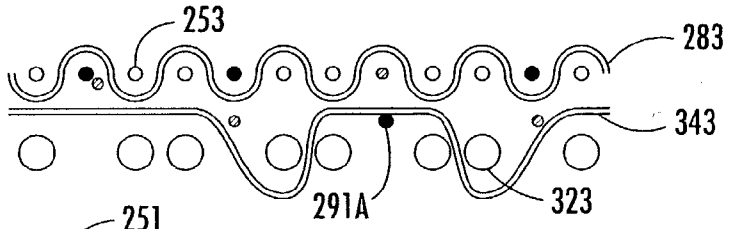

FIG. 15G.

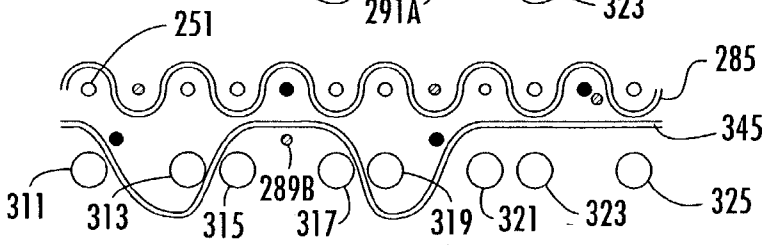

FIG. 15H.

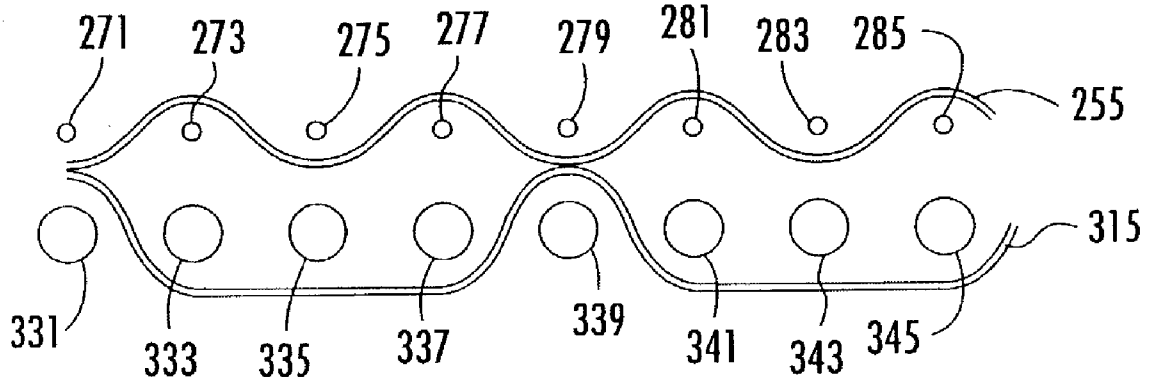

FIG. 16A.

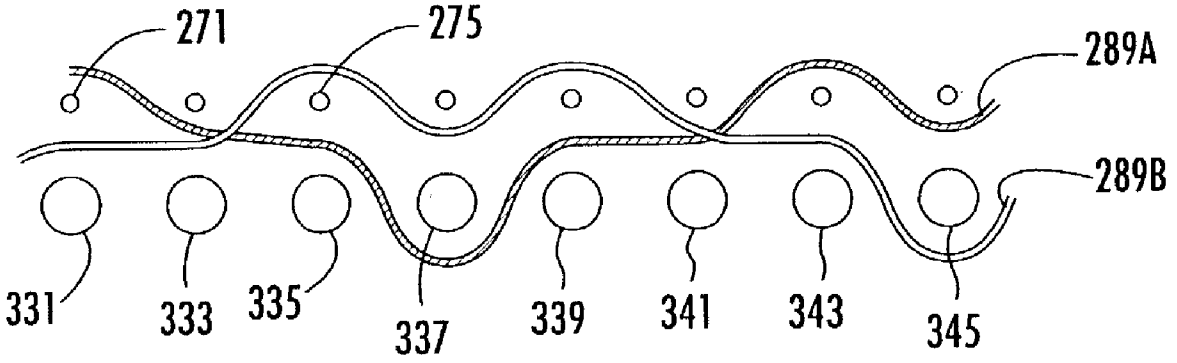

FIG. 16B.

PAPERMAKER'S FORMING FABRIC

FIELD OF THE INVENTION

[0001] This invention relates generally to woven fabrics, and relates more specifically to woven fabrics for papermakers.

BACKGROUND OF THE INVENTION

[0002] In the conventional fourdrinier papermaking process, a water slurry, or suspension, of cellulosic fibers (known as the paper "stock") is fed onto the top of the upper run of an endless belt of woven wire and/or synthetic material that travels between two or more rollers. The belt, often referred to as a "forming fabric", provides a papermaking surface on the upper surface of its upper run which operates as a filter to separate the cellulosic fibers of the paper stock from the aqueous medium, thereby forming a wet paper web. The aqueous medium drains through mesh openings of the forming fabric, known as drainage holes, by gravity alone or with assistance from one or more suction boxes located on the lower surface (i.e., the "machine side") of the upper run of the fabric.

[0003] After leaving the forming section, the paper web is transferred to a press section of the paper machine, in which it is passed through the nips of one or more pairs of pressure rollers covered with another fabric, typically referred to as a "press felt." Pressure from the rollers removes additional moisture from the web; the moisture removal is often enhanced by the presence of a "batt" layer on the press felt. The paper is then conveyed to a drier section for further moisture removal. After drying, the paper is ready for secondary processing and packaging.

[0004] Typically, papermaker's fabrics are manufactured as endless belts by one of two basic weaving techniques. In the first of these techniques, fabrics are flat woven by a flat weaving process, with their ends being joined to form an endless belt by any one of a number of well-known joining methods, such as dismantling and reweaving the ends together (commonly known as splicing), or sewing a pin-seamable flap on each end or a special foldback, then reweaving these into pin-seamable loops. In a flat woven papermaker's fabric, typically the warp yarns extend in the machine direction and the filling yarns extend in the cross machine direction. In the second technique, fabrics are woven directly in the form of a continuous belt with an endless weaving process. In the endless weaving process, the warp yarns extend in the cross machine direction and the filling yarns extend in the machine direction. As used herein, the terms "machine direction" (MD) and "cross machine direction" (CMD) refer, respectively, to a direction aligned with the direction of travel of the papermaker's fabric on the papermaking machine, and a direction parallel to the fabric surface and traverse to the direction of travel. Both weaving methods described hereinabove are well known in the art, and the term "endless belt" as used herein refers to belts made by either method.

[0005] Effective sheet and fiber support and an absence of wire marking are typically important considerations in papermaking, especially for the forming section of the papermaking machine, where the wet web is initially formed. Wire marking is particularly problematic in the formation of fine paper grades, as it can affect a host of paper properties, such as sheet mark, porosity, "see through" and pin holing. Wire marking is typically the result of individual cellulosic fibers being oriented within the paper web such that their ends reside within gaps between the individual threads or yarns of the forming fabric. This problem is generally addressed by providing a permeable fabric structure with a coplanar surface that allows paper fibers to bridge adjacent yarns of the fabric rather than penetrate the gaps between yarns. As used herein, "coplanar" means that the upper extremities of the yarns defining the paper-forming surface are at substantially the same elevation, such that at that level there is presented a substantially "planar" surface. Accordingly, fine paper grades intended for use in quality printing, carbonizing, cigarettes, electrical condensers, and like grades of fine paper have typically heretofore been formed on very finely woven or fine wire mesh forming fabrics.

[0006] Typically, such finely woven fabrics include at least some relatively small diameter machine direction or cross machine direction yarns. Regrettably, however, such yarns tend to be delicate, leading to a short surface life for the fabric. Moreover, the use of smaller yarns can also adversely effect the mechanical stability of the fabric (especially the skew resistance, propensity for narrowing and stiffness), which may negatively impact both the service life and the performance of the fabric.

[0007] To combat these problems associated with fine weaves, multi-layer forming fabrics have been developed with fine-mesh yarns on the paper-forming surface to facilitate paper formation and coarser-mesh yarns on the machine contact side to provide strength and durability. For example, fabrics have been constructed which employ one set of machine direction yarns which interweave with two sets of cross machine direction yarns to form a fabric having a fine paper forming surface and a more durable machine side surface. These fabrics form part of a class of fabrics which are generally referred to as "double layer" fabrics. Similarly, fabrics have been constructed which include two sets of machine direction yarns and two sets of cross machine direction yarns that form a fine mesh paper side fabric layer and a separate, coarser machine side fabric layer. In these fabrics, which are part of a class of fabrics generally referred to as "triple layer" fabrics, the two fabric layers are typically bound together by separate stitching yarns. As double and triple layer fabrics include additional sets of yarn as compared to single layer fabrics, these fabrics typically have a higher "caliper" (i.e., they are thicker than) comparable single layer fabrics. An illustrative double layer fabric is shown in U.S. Pat. No. 4,423,755 to Thompson, and illustrative triple layer fabrics are shown in U.S. Pat. No. 4,501,303 to Osterberg, U.S. Pat. No. 5,152,326 to Vohringer, U.S. Pat. Nos. 5,437,315 5,967,195, and 6,145,550 to Ward, and U.S. Pat. No. 6,244,306 to Troughton, the disclosures of which are hereby incorporated by reference in their entirety.

[0008] Although these fabrics have performed successfully, they have some potential shortcomings that may relate to the inclusion of the stitching yarns, for example, problems with interlayer wear. As the fabric is used on a paper machine, the top and bottom layers tend to shift relative to one another, both in the machine direction and the cross machine direction, due to the tension imparted to the fabric by the rolls. This effect is exacerbated on paper machines,

such as the so-called "high-wrap" machines, that include multiple rolls, including some which contact the top layer of the fabric. This shifting can cause the fabric to wear and decrease in thickness, which can adversely affect the drainage of the fabric and, accordingly, its performance in papermaking. In many instances, it is this interlayer wear, rather than the wear of the machine side surface of the fabric machine against the paper machine, that determines the longevity of the fabric.

[0009] Also, the stitching yarns of a triple layer fabric should be sufficiently strong and durable to bind the top and bottom layers and to resist the wear and abrasion conditions that the bottom layer experiences while in contact with the paper machine, yet should be delicate enough to produce high quality paper. This balance can be difficult to strike.

SUMMARY OF THE INVENTION

[0010] The present invention is directed to papermaker's fabrics that can address some of the wear and abrasion issues noted above. In certain embodiments according to the present invention, a papermaker's fabric includes top MD yarns, top CMD yarns, bottom MD yarns, bottom CMD yarns and stitching yarns. The fabric is formed in a plurality of repeating units, each of the repeating units including a set of top MD yarns, a set of top CMD yarns interwoven with the set of top MD yarns to form a top fabric layer, a set of four bottom MD yarns, a set of bottom CMD yarns interwoven with the set of four bottom MD yarns to form a bottom fabric layer and a set of stitching yarns interwoven with the top and bottom fabric layers. The bottom MD yarns and the bottom CMD yarns are interwoven in a series of repeat units in which each of the bottom MD yarns passes below two nonadjacent bottom CMD yarns to form bottom machine direction knuckles, each bottom machine direction knuckle being separated from one adjacent knuckle formed by that bottom machine direction yarn by two bottom CMD yarns and separated from another adjacent knuckle also formed by that bottom MD yarn by four bottom CMD yarns. In this configuration, the bottom MD yarns present stitching locations for the stitching yarns that can be very favorable for avoiding abrasion and wear. The stitching locations form a symmetrical pattern that may be easier to manufacture.

[0011] In other embodiments according to the present invention, the papermaker's fabric discussed above includes pairs of first and second stitching yarns positioned between pairs of top CMD yarns. The first and second stitching yarns of each pair are interwoven with the top and bottom MD yarns such that, as a fiber support portion of the first stitching yarn is interweaving with the top MD yarns, a binding portion of the second stitching yarn is positioned below the top MD yarns, and such that as a fiber support portion of the second stitching yarn is interweaving with the top MD yarns, a binding portion of the first stitching yarn is positioned below the top MD yarns. The first and second stitching yarns cross each other as they pass below a transitional top MD yarn, and each of the binding portions of the first and second stitching yarns passes below at least one of the bottom MD yarns.

[0012] In other embodiments of the present invention, embodiments of the papermaker's fabrics described above may be used to make paper. A paper stock may be applied to a papermaker's fabric as described above, and moisture may be removed from the paper stock to produce paper.

BRIEF DESCRIPTION OF THE FIGURES

[0013] **FIG. 1** is a top view of a triple layer forming fabric of the present invention.

[0014] **FIG. 2** is a top section view of the bottom layer of the fabric of **FIG. 1** with the top layer removed.

[0015] **FIG. 3** is a section view taken along line **3-3** shown in **FIGS. 1 and 2** of the fabric thereof.

[0016] FIGS. **4**A-B are section views taken along, respectively, lines **4**A-**4**A and **4**B-**4**B shown in **FIGS. 1 and 2** of the fabric thereof.

[0017] **FIG. 5** is a top view of another embodiment of a triple layer forming fabric of the present invention.

[0018] **FIG. 6** is a top section view of the bottom layer of the fabric of **FIG. 5** with the top layer removed.

[0019] **FIG. 7** is a section view taken along line **7-7** shown in **FIGS. 5 and 6** of the fabric thereof.

[0020] FIGS. **8**A-**8**B are section views taken along, respectively, lines **8**A-**8**A and **8**B-**8**B shown in **FIGS. 5 and 6** of the fabric thereof.

[0021] **FIG. 9** is a top view of still another embodiment of a triple layer forming fabric of the present invention having pairs of stitching yarns.

[0022] **FIG. 10** is a top section view of the bottom layer of the fabric of **FIG. 9** with the top layer removed.

[0023] FIGS. **11**A-**11**H are section views taken along, respectively, lines **11**A-**11**A through **11**H-**11**H shown in **FIGS. 9 and 10** of the fabric thereof.

[0024] FIGS. **12**A-**12**B are section views taken along, respectively, lines **12**A-**12**A and **12**B-**12**B shown in **FIGS. 9 and 10** of the fabric thereof.

[0025] **FIG. 13** is a top view of a further embodiment of a triple layer forming fabric of the present invention having pairs of stitching yarns.

[0026] **FIG. 14** is a top section view of the bottom layer of the fabric of **FIG. 13** with the top layer removed.

[0027] FIGS. **15**A-**15**H are section views taken along, respectively, lines **15**A-**15**A through **15**H-**15**H shown in **FIGS. 13 and 14** of the fabric thereof.

[0028] FIGS. **16**A-**16**B are section views taken along, respectively, lines **16**A-**16**A and **16**B-**16**B shown in **FIGS. 13 and 14** of the fabric thereof.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0029] The present invention will now be described more particularly hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. The invention, however, be embodied in many different forms and is not limited to the embodiments set forth herein; rather, these embodiments are provided so that the disclosure will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like components throughout. The dimensions and thicknesses for some elements and the spacing between elements may be exaggerated for clarity.

[0030] An eight harness triple layer forming fabric, generally designated at **10**, is illustrated in **FIGS. 1, 2**, and **3**A-3C, in which a single repeat unit of the fabric **10** is shown. The repeat unit of the fabric **10** includes a top layer **60** and a bottom layer **80**. The top layer **60** includes eight top MD yarns **11**, **13**, **15**, **17**, **19**, **21**, **23**, and **25** and eight top CMD yarns **31**, **33**, **35**, **37**, **39**, **41**, **43**, and **45**. These are interwoven such that each top CMD yarn passes over and beneath top MD yarns in an alternating fashion, with adjacent top CMD yarns being offset by one top MD yarn to form a plain weave pattern. For example, top CMD yarn **35** passes over top MD yarn **11**, under top MD yarn **13**, over top MD yarn **15**, under top MD yarn **17** and so on until it passes under top MD yarn **25**. Top MD yarn **11** passes under top CMD yarn **31**, over top CMD yarn **33**, under top CMD yarn **35**, over top CMD yarn **39** and so on until it passes under top CMD **45**. Stitching yarns **51**, **53**, **55** and **57** pass over various MD yarns to stitch the top layer **60** of the fabric **10** to the bottom layer **80** in a manner described in detail below.

[0031] Referring now to **FIG. 2**, the repeat unit of the fabric **10** also includes the bottom layer **80**. The bottom layer **80** includes eight bottom MD yarns **61**, **63**, **65**, **67**, **69**, **71**, **73**, and **75**, which are interwoven with eight bottom CMD yarns **81**, **83**, **85**, **87**, **89**, **91**, **93**, and **95**. In this embodiment, each of the bottom MD and CMD yarns is positioned substantially directly below a corresponding top MD or CMD yarn, although weave patterns in which such is not the case are possible. The bottom MD yarns are interwoven with the bottom CMD yarns in a pattern in which each bottom MD yarn passes under one bottom CMD yarn, over four adjacent bottom CMD yarns, below the next bottom CMD yarn, and over the next two adjacent bottom CMD yarns. For example, bottom MD yarn **63** passes below bottom CMD yarn **81**, above bottom CMD yarns **83**, **85**, **87**, and **89**, below bottom CMD yarn **91**, above bottom CMD yarns **93** and **95**. The other bottom MD yarns follow a similar "under 1/over 4/under 1/over 2" weave pattern, but each is offset in its weaving sequence from its nearest bottom MD yarn neighbors by two bottom CMD yarns. Consequently, bottom MD yarn **61** (which is adjacent bottom MD yarn **63**) passes below bottom CMD yarn **85**, above bottom CMD yarns **87**, **89**, **91**, and **93**, below bottom CMD yarn **95**, and above bottom CMD yarns **81** and **83**. Thus, the bottom MD "knuckle" formed by bottom MD yarn **63** as it passes below bottom CMD yarn **91** is offset from the bottom "knuckle" formed by bottom MD yarn **61** as it passes below bottom CMD yarn **95** by two bottom CMD yarns.

[0032] The bottom CMD yarns follow an "over 1/under 3" pattern that is repeated twice within the repeat unit. The bottom layer **80** has a repeat unit of four bottom MD yarns. For example, bottom CMD yarn **85** passes over bottom MD yarn **61**, under bottom MD yarns **63**, **65**, and **67**, over bottom MD yarn **69** and under bottom MD yarns **71**, **73** and **75**, while bottom CMD yarn **87** passes over bottom MD yarn **65**, under bottom MD yarns **67**, **69**, and **71**, over bottom MD yarn **73**, and under bottom MD yarns **75**, **61** and **63**.

[0033] Referring back to **FIG. 1**, and also referring to **FIG. 2**, the top layer **60** includes portions of four stitching yarns **51**, **53**, **55**, and **57**. The stitching yarns **51**, **53**, **55**, and **57** are positioned between adjacent top and bottom CMD yarns such that each stitching yarn is separated from an adjacent stitching yarn by two top and two bottom CMD yarns. For example, stitching yarn **51** is separated from stitching yarn **53** by top CMD yarns **33** and **34** and bottom CMD yarns **83** and **85**.

[0034] As can be seen in **FIGS. 3 and 4**A-B, stitching yarns interweave with the top MD yarns and bottom MD yarns in the following pattern. Each of the stitching yarns of the repeat unit can be subdivided into two portions: an upper portion which interweaves with the top MD yarns, and a lower portion which interweaves with a bottom MD yarn. As discussed above, the bottom MD yarns form an "under 1/over 4/under 1/over 2" weave pattern. Thus, the bottom MD yarns form knuckles under nonadjacent bottom CMD yarns such that each knuckle is separated from adjacent knuckles by two bottom CMD yarns one side and four bottom CMD yarns on the other. For example, in **FIG. 3**, bottom MD yarn **63** forms knuckles with bottom CMD yarns **81** and **91**. The knuckles are separated by four bottom CMD yarns **83**, **85**, **87** and **89** on one side and by two bottom CMD yarns **93** and **95** on the other side.

[0035] The stitching yarns are interwoven relative to the bottom MD yarns such that the lower portion of each stitching yarn forms a binding knuckle with the bottom MD yarn between the second and third of the four bottom CMD yarns separating two adjacent bottom MD knuckles. For example, bottom MD yarn **63** forms knuckles with CMD yarns **81** and **91**. The knuckles are separated by four bottom CMD yarns **83**, **85**, **87** and **89**. A stitching yarn **53** forms a knuckle with the bottom MD yarn **63** between the second and third of the four bottom CMD yarns, that is, bottom CMD yarns **85** and **87** (e.g., **FIG. 3**). It has been discovered that, in this configuration, the stitching yarns may be better protected from wear. The bottom MD yarn **63**"floats" between the bottom CMD yarns **81** and **91** and arches somewhat above the four bottom CMD yarns **83**, **85**, **87** and **89**. Thus, placing the stitching yarn **53** in a position that is central to the "arch" of the bottom MD yarn **63** (between bottom CMD yarns **85** and **87**) may allow protection from wear because stitching yarn **53** is then located some distance from the lower surface of the bottom layer **80**, thereby reducing wear on the stitching yarn **53**. Each of the other stitching yarns **51**, **53**, **55**, **57** also binds below a bottom MD yarn between the second and third yarns of a four yarn float found by that bottom MD yarn.

[0036] **FIGS. 5, 6, 7** and **8**A-8B illustrate an alternative embodiment of a triple layer fabric designated broadly at **100**. The triple layer fabric **100** includes a top layer **110** and a bottom layer **120**. The top layer **110** includes eight top MD yarns **481**, **483**, **485**, **487**, **489**, **491**, **493** and **495** interwoven with eight top CMD yarns **461**, **463**, **465**, **467**, **469**, **471**, **473** and **475**, as well as stitching yarns **97**, **99**, **101**, and **103**. The top CMD yarns and the top MD yarns are interwoven to form a plain weave surface similar to that in the fabric **10** described above. The top CMD yarns and the stitching yarns are arranged such that a stitching yarns follows every two top CMD yarns in repeating pattern. For example, stitching yarn **97** is separated from stitching yarn **99** by top CMD yarns **463** and **465**, and stitching yarn **99** is separated from stitching yarn **101** by top CMD yards **467** and **469**, and so on.

[0037] The bottom layer **120** includes eight bottom MD direction yarns **131**, **133**, **135**, **137**, **139**, **141**, **143** and **145** interwoven with eight bottom CMD yarns **111**, **113**, **115**,

117, **119**, **121**, **123**, and **125**. The weaving pattern of the bottom MD yarns relative to the bottom CMD yarns is identical to that described above for the fabric **10**, namely, each bottom MD yarn follows an "under 1/over 4/under 1/over 2" pattern relative to the bottom CMD yarn, and adjacent bottom MD yarns are offset from one another by two bottom CMD yarns. As a result, the characteristic bottom MD knuckles formed under bottom CMD yarns are separated from one another by, alternately, four bottom CMD yarns on one side of a knuckle and two bottom CMD yarns on the other side of a knuckle, similar to fabric **10** discussed above.

[**0038**] As with fabric **10**, the stitching yarns are interwoven with bottom MD yarns to form binding knuckles between the knuckles formed by the bottom MD yarns and the bottom CMD yarns. However, the binding knuckles formed by the stitching yarns and bottom MD yarns in fabric **100** are formed between two bottom CMD yarns that separate two bottom MD yarn knuckles. For example, in **FIG. 7**, stitching yarn **97** forms a binding knuckle with bottom MD yarn **131**. The binding knuckle is located between bottom CMD yarns **111** and **113**. Bottom MD yarn **131** in turn forms knuckles with bottom CMD yarns **115** and **125**. These knuckles at bottom CMD yarns **125** and **115** are separated from one another by bottom CMD yarns **111** and **113**.

[**0039**] The performance advantages discussed above for fabric **10** may also be achieved with fabric **100**. Specifically, the binding knuckles are located between two bottom CMD yarns, which in turn separate two bottom CMD/MD yarn knuckles. Thus, the bottom CMD yarns on either side of the binding knuckle can protect the stitching yarns from contact with the paper machine and from the resulting wear. By being so located, the binding knuckles are located at the apex of the float that the bottom MD yarns form over the bottom CMD yarns. Therefore, the binding knuckles are positioned away from the lower surface of the bottom layer **120**, and are less susceptible to contact with the paper machine and the resulting wear.

[**0040**] As would be appreciated by those of skill in the art, various top fabric layer configurations and weave patterns may be substituted for the top layers **60** and **110** discussed above. For example, in fabrics **10** and **100**, when either of the bottom layers **80** and **120** are joined with the respective top layers **60** and **110**, each of the bottom CMD yarns is positioned substantially directly below a corresponding top CMD yarn. There is no bottom CMD yarn positioned substantially directly below the stitching yarn, thereby providing a space in which the stitching yarns can stitch below a bottom CMD yarn. Of course, those skilled in this art will appreciate that the fabric may have differing numbers of top and bottom CMD yarns in a repeat unit; for example, there may be 1.5, two or three times as many top CMD yarns as bottom CMD yarns, or there may be a CMD yarn below each stitching yarn. Also, the top layers **60** and **110** may vary from plain weave patterns illustrated herein; for example, the pattern of the top layer may be satin, twill, broken twill, or the like.

[**0041**] Those skilled in this art will appreciate that, although the illustrated fabrics employ a single stitching yarn, stitching yarn pairs may also be employed. Stitching yarn pairs can be incorporated into the paper making surface of the fabric as is disclosed in U.S. Pat. No. 6,145,550 to Ward. Examples of triple layer fabrics using stitching yarn pairs is illustrated are FIGS. **9-16**B.

[**0042**] One example of a triple layer fabric, designated **170**, is shown in **FIGS. 9, 10, 11**A-H, and **12**A-**12**B. The fabric **170** has a top layer **150** and a bottom layer **200**, which are stitched together by stitching yarn pairs **187**A, **187**B, **189**A, **189**B, **191**A, **191**B, **193**A and **193**B. The top layer **150** includes top MD yarns **171**, **173**, **175**, **177**, **179**, **181**, **183** and **185** interwoven with eight top CMD yarns **151**, **153**, **155**, **157**, **159**, **161**, **163** and **165**. The top MD yarns are interwoven with the top CMD yarns and the stitching yarns in an "over/under" pattern. For example, top MD yarn **173** passes over top CMD yarn **151**, under stitching yarn **187**B, over top CMD yarn **153**, under top CMD yarn **155** and so forth until it passes under top CMD yarn **165**. Thus, the stitching yarns pairs **187**A, **187**B, **189**A, **189**B, **191**A, **191**B, **193**A, and **193**B form an integral part of the top layer **150**.

[**0043**] The bottom layer **200** of the fabric **170** is substantially identical to the bottom layers **80** and **120** illustrated in **FIGS. 2 and 6**. That is, the bottom layer **200** includes eight bottom MD direction yarns **231**, **233**, **235**, **237**, **239**, **241**, **243**, and **245** interwoven with eight bottom CMD yarns **211**, **213**, **215**, **217**, **219**, **221**, **223**, and **225**. Like bottom layers **80** and **120**, the bottom layer **200** in **FIG. 10** is interwoven in an "under 1/over 4/under 1/over 2" pattern. Each knuckle formed from a bottom MD yarn passing under a bottom CMD yarn is separated from its bottom MD adjacent knuckle by two bottom CMD yarns on one side and four bottom CMD yarns on the other side. Each bottom MD yarn is offset from its adjacent bottom MD yarns by two bottom CMD yarns.

[**0044**] Corresponding pairs of stitching yarns in fabric **170** interweave with the top MD yarns and bottom MD yarns in the following pattern. Each of the stitching yarns of the repeat unit can be subdivided into two portions: a fiber support portion which interweaves with the top MD yarns, and a binding portion which interweaves a bottom MD yarn. These are separated at "transitional" top MD yarns, below which one stitching yarn of a pair crosses the other stitching yarn of the pair. The stitching yarns of each pair are interwoven relative to one another such that the fiber support portion of one yarn of the pair is positioned substantially above the binding portion of the other yarn of the pair. The fiber support portion of the stitching yarn of each pair designated with an "A" (e.g., **187**A, **189**A, **191**A, **193**A) interweaves in an alternating fashion with three top MD yarns in an over/under pattern as the other stitching yarn of the pair (for purposes of this example, designated with a "B") forms a binding knuckle with one bottom MD yarn.

[**0045**] For example, in **FIG. 12**B, stitching yarn **189**A passes over top MD yarn **171**, under top MD yarn **173**, over top MD yarn **175**, and intersects with stitching yarn **189**B beneath transitional top MD yarn **177** and above bottom MD yarn **237**. Beneath this fiber support portion of stitching yarn **189**A, which forms the "over/under" pattern with top MD yarns **171**, **173**, and **175**, stitching yarn **189**B passes over bottom MD yarn **231**, under bottom MD yarn **233**, and over bottom MD yarn **235** to form a binding knuckle at bottom MD yarn **233**. The pattern for stitching yarns **189**A and **189**B is reversed for top MD yarns **179**, **181**, **183**, and **185**, where the fiber support portion of the stitching yarn **189**B is

located, and bottom MD yarns **239**, **241**, **243**, and **245**, where the binding portion of stitching yarn **189**A is located. Conversely, the fiber support portion of the stitching yarn of each pair designated with a "B" (e.g., **187**B, **189**B) interweaves in an alternating fashion with three top MD yarns in an "over/under" pattern as the other stitching yarns of the pair (designated with an "A") forms a binding knuckle with one bottom MD yarn.

[**0046**] As can be seen, for example, in FIGS. **11**A-**11**H, the stitching yarns form binding knuckles between the second and third of the four bottom CMD yarns separating bottom MD knuckles formed between bottom CMD yarns and a single bottom MD yarn. For example, in **FIG. 11**A, bottom MD yarn **231** passes over bottom CMD yarns **211** and **213**, under bottom CMD yarn **215**, over bottom CMD yarns **217**, **219**, **221** and **223**, and under bottom CMD yarn **225**. Thus, bottom MD yarn **231** forms bottom MD knuckles below bottom CMD yarns **215** and **225**, which are separated by four bottom CMD yarns **217**, **219**, **221** and **223** on one side and two bottom CMD yarns **211** and **213** on the other. Stitching yarn **191**A forms a binding knuckle under bottom MD yarn **231** between bottom CMD yarns **219** and **221**, which are the second and third of the four bottom CMD yarns **217**, **219**, **221** and **223** that separate the two knuckles. All binding knuckles are similarly placed between the second and third bottom CMD yarns of the four bottom CMD yarns between bottom MD knuckles. As discussed with respect to fabric **10**, such a placement of the binding knuckle may protect the stitching yarn, which is located equidistant from the two knuckles and beneath the highest portion of the float formed by the bottom MD yarn **231**.

[**0047**] Another example of a triple layer fabric **250** having pairs of stitching yarns is shown in FIGS. **13**-**16**B. The top layer **270** of the fabric **250** includes a eight top MD yarns **271**, **273**, **275**, **277**, **279**, **281**, **283** and **285** interwoven with eight top CMD yarns **251**, **253**, **255**, **257**, **259**, **261**, **263**, and **265** similar to the pattern shown in top layer **150** in **FIG. 7**; i.e., the top MD and top CMD yarns are interwoven with stitching yarn pairs **287**A, **287**B, **289**A, **289**B, **291**A, **291**B, **293**A and **293**B in an "over/under" plain weave pattern.

[**0048**] The bottom layer **300** in **FIG. 14** includes eight bottom MD yarns **331**, **333**, **335**, **337**, **339**, **341**, **343** and **345** interwoven with eight bottom CMD yarns **311**, **313**, **315**, **317**, **319**, **321**, **323** and **325** in a pattern similar to bottom layers **80** in **FIG. 2**, **120** in **FIGS. 6 and 200** in **FIG. 10**. Each bottom MD yarn forms knuckles with two non-adjacent bottom CMD yarns that are separated from each other by four bottom CMD yarns on one side and two bottom CMD yarns on the other.

[**0049**] The stitching yarn pairs follow a pattern similar to that described with respect to fabric **170**. As can be seen in **FIGS. 13 and 14**, and in particular **FIG. 16**B, each stitching yarn alternately forms a binding knuckle with the bottom layer as its companion yarn of the stitching yarn pair interweaves with the top layer. For example, stitching yarn **289**A forms a knuckle with bottom MD yarn **337** as stitching yarn **289**B interweaves with the top layer **270** by passing over top MD yarn **275**, under top MD yarn top **277**, over top MD yarn **279** and crossing stitching yarn **289**A below transitional top MD yarn **281** and above bottom MD yarn **341**. However, in this fabric embodiment, the stitching yarns form binding knuckles between two bottom CMD yarns separating bottom MD yarn knuckles.

[**0050**] As an example and as shown in **FIG. 15**A, bottom MD yarn **331** passes over bottom CMD yarns **311** and **313**, under bottom CMD yarn **315**, over bottom CMD yarns **317**, **319**, **321** and **323**, and under bottom CMD yarn **325**. Knuckles are formed by bottom MD yarn **331** at bottom CMD yarns **325** and **315**. The stitching yarn **287**A forms a binding knuckle with bottom MD yarn **331** between two bottom CMD yarns **311** and **313**, which separate the knuckles at bottom CMD yarns **325** and **315**. As discussed with respect to fabric **100** in FIGS. **5**-**8**B, placement of the binding knuckle between two bottom CMD yarns that separate bottom MD knuckles may protect the stitching yarn from the papermaking surface.

[**0051**] The stitching yarn pairs shown in fabrics **170** and **250** in FIGS. **9**-**16**B are stitched in a "reversed picks" configuration. The "reversed picks" configuration is described in detail in U.S. Pat. Nos. 5,967,195 and 6,145,550 to Ward. To summarize for the present invention, the presence of reversed picks in a double-pick-stitched triple layer fabric can be established by locating the transitional top MD yarns and determining the most predominant diagonal formed by the transitional top MD yarns, the most predominant diagonal being the diagonal having the minimum number of steps between transitional top MD yarns. If the fiber support portions of successive stitch yarn pairs on one side of this diagonal are closer to each other in some cases and further apart in others, then the fabric can be said to have at least some "reversed picks" in the stitching yarn configuration. Although it is preferred that all of the stitching yarn pairs follow this pattern, i.e., that 50% of the stitching yarn pairs be "reversed", some benefit can be obtained by reversing only a smaller percentage (for example 25, 33 or 40%) of the stitching yarn pairs.

[**0052**] Other stitching yarn configurations can be used. For example, the stitching yarns may be "pseudo-stitching" yarn pairs. In a pseudo-stitching yarn configuration, only one of the yarns in a stitching yarn pair forms a knuckle with the bottom MD yarns. Referring to **FIG. 12**B, the stitching yarns **189**A and **189**B could be modified to be pseudo-stitching yarns if only one of the stitching yarns **189**A and **189**B stitched underneath bottom MD yarn **233** or **241**. For example, in a pseudo-stitching yarn configuration, if stitching yarn **189**B passes underneath bottom MD yarn **233**, then stitching yarn **189**A would be modified from **FIG. 12B** to pass above bottom MD yarn **241**. As another example of an alternative stitching yarn configuration with reference to **FIGS. 4B and 8B**, the stitching yarns **53** and **99** may interlace with the bottom MD yarns only once in the repeat unit. For example, stitching yarn **53** may be configured such that it passes over top of bottom MD yarn **63** and under top MD yarn **13**, rather than stitching underneath bottom MD yarn **63** as shown. In addition, or alternatively, the stitching yarns may not interlace with the top MD yarns as frequently as shown.

[**0053**] As would be understood by those of ordinary skill in the art, the weave patterns described with reference to FIGS. **1**-**8**B may be woven with either four or eight harnesses on the paper side (top layer) and either four or eight harnesses on the machine side (bottom layer) of the fabric. Certain variations of the weave patterns shown in FIGS. **1**-**8**B may require eight harnesses. For example, if the stitching yarn **53** in **FIG. 4B** is configured so that it only interlaces with one of the bottom MD yarns **63** or **71**, then

eight harnesses are needed. As used herein, it should be understood that weave patterns described with reference to four harnesses (or four CMD or four MD yarns) include weave patterns with eight harnesses, i.e., two sets of four harnesses. The weave patterns described with reference to FIGS. **9-16**B are generally woven with eight harnesses.

[**0054**] Although illustrated embodiments employ plain weave pattern top layers, the fabrics of the present invention may also employ other top layer weave patterns; for example, satins, broken twills, and the like may also be employed. The stitching yarns may comprise an integral portion of the top surface weave or may not.

[**0055**] The form of the yarns utilized in the fabrics of the present invention can vary, depending upon the desired properties of the final papermaker's fabric. For example, the yarns may be multifilament yarns, monofilament yarns, twisted multifilament or monofilament yarns, spun yarns, or any combination thereof. Also, the materials comprising yarns employed in the fabric of the present invention may be those commonly used in papermaker's fabric. For example, the yarns may be formed of polypropylene, polyester, aramid, nylon, or the like. The skilled artisan should select a yarn material according to the particular application of the final fabric. In particular, round monofilament yarns formed of polyester or nylon are preferred.

[**0056**] Yarn sizes should also be selected according to the desired papermaking properties of the fabric. As an example, generally, for fine paper applications, top MD yarns have a diameter of between about 0.13 mm and 0.17 mm, top CMD yarns have a diameter of between about 0.13 mm and 0.20 mm, stitching yarns have a diameter of between about 0.11 mm and 0.15 mm, bottom MD yarns-have a diameter of between about 0.17 mm and 0.25 mm, and bottom CMD yarns have a diameter of between about 0.20 mm and 0.35 mm.

[**0057**] The foregoing embodiments are illustrative of the present invention, and are not to be construed as limiting thereof. The invention is defined by the following claims, with equivalents of the claims to be included therein.

That which is claimed is:

1. A papermaker's fabric, comprising top machine direction yarns, top cross machine direction yarns, bottom machine direction yarns, bottom cross machine direction yarns and stitching yarns, the fabric being formed in a plurality of repeating units, each of the repeating units comprising:

a set of top machine direction yarns;

a set of top cross machine direction yarns interwoven with the set of top machine direction yarns to form a top fabric layer;

a set of four bottom machine direction yarns;

a set of bottom cross machine direction yarns interwoven with the set of bottom machine direction yarns to form a bottom fabric layer; and

a set of stitching yarns interwoven with the top and bottom fabric layers;

wherein the bottom machine direction yarns and the bottom cross machine direction yarns are interwoven in a series of repeat units in which each of the bottom machine direction yarns passes below two nonadjacent bottom cross machine direction yarns to form bottom machine direction knuckles, each bottom machine direction knuckle being separated from one adjacent knuckle formed by that bottom machine direction yarn by two bottom cross machine direction yarns and separated from another adjacent knuckle by four bottom cross machine direction yarns.

2. The papermaker's fabric defined in claim 1, wherein each of the stitching yarns forms a binding knuckle with one of the bottom machine direction yarns between adjacent knuckles.

3. The papermaker's fabric defined in claim 2, wherein each of the binding knuckles is located between the two cross machine direction yarns separating two adjacent bottom machine direction knuckles.

4. The papermaker's fabric defined in claim 2, wherein each of the binding knuckles is located between a second and third of the four bottom cross machine direction yarns separating two adjacent bottom machine direction knuckles.

5. The papermaker's fabric defined in claim 1, wherein each of the bottom machine direction yarns is offset from adjacent bottom machine direction yarns by two bottom cross machine direction yarns.

6. The papermaker's fabric defined in claim 1, wherein the set of stitching yarns comprises pairs of first and second stitching yarns positioned between pairs of adjacent top cross machine direction yarns.

7. The papermaker's fabric defined in claim 1, wherein the set of stitching yarns comprises one stitching yarn between pairs of adjacent top CMD yarns.

8. The papermaker's fabric defined in claim 1, wherein the set of top machine direction yarns comprises fourtop machine direction yarns.

9. The papermaker's fabric defined in claim 1, wherein the set of bottom cross machine direction yarns comprises four or eight bottom cross machine direction yarns.

10. A papermaker's fabric, comprising top machine direction yarns, top cross machine direction yarns, bottom machine direction yarns, bottom cross machine direction yarns and stitching yarns, the fabric being formed in a plurality of repeating units, each of the repeating units comprising:

a set of top machine direction yarns;

a set of top cross machine direction yarns interwoven with the set of top machine direction yarns to form a top fabric layer;

a set of eight bottom machine direction yarns;

a set of bottom cross machine direction yarns interwoven with the set of bottom machine direction yarns to form a bottom fabric layer; and

sets of first and second stitching yarns interwoven with the top and bottom fabric layers; and

wherein the bottom machine direction yarns and the bottom cross machine direction yarns are interwoven in a series of repeat units in which each of the bottom machine direction yarns passes below two nonadjacent bottom cross machine direction yarns to form bottom machine direction knuckles, each bottom machine direction knuckle being separated from one adjacent knuckle formed by that bottom machine direction yarn

by two cross bottom machine direction yarns and separated from another adjacent knuckle formed by that bottom machine direction yarn by four bottom cross machine direction yarns; and

wherein pairs of first and second stitching yarns are positioned between pairs of top cross machine direction yarns, the first and second stitching yarns of each pair being interwoven with the top and bottom machine direction yarns, such that, as a fiber support portion of the first stitching yarn is interweaving with the top machine direction yarns, a binding portion of the second stitching yarn is positioned below the top machine direction yarns, and such that as a fiber support portion of the second stitching yarn is interweaving with the top machine direction yarns, a binding portion of the first stitching yarn is positioned below the top machine direction yarns, and such that the first and second stitching yarns cross each other as they pass below a transitional top machine direction yarn, and such that each of the binding portions of the first and second stitching yarns passes below at least one of the bottom machine direction yarns.

11. The papermaker's fabric defined in claim 10, wherein between 25 and 50 percent of adjacent pairs of first and second stitching yarns are interwoven as reversed picks.

12. The papermaker's fabric defined in claim 10, wherein each of the first and second stitching yarns forms a binding knuckle with one of the bottom machine direction yarns between adjacent bottom machine direction knuckles.

13. The papermaker's fabric defined in claim 12, wherein each of binding knuckles is located between the two cross machine direction yarns separating two adjacent bottom machine direction knuckles.

14. The papermaker's fabric defined in claim 12, wherein each of the binding knuckles is located between a second and third of the four cross machine direction yarns separating two adjacent knuckles.

15. The papermaker's fabric defined in claim 10, wherein each of the bottom machine direction yarns is offset from adjacent bottom machine direction yarns by two bottom cross machine direction yarns.

16. The papermaker's fabric defined in claim 10, wherein the set of top machine direction yarns comprises eight top machine direction yarns.

17. The papermaker's fabric defined in claim 10, wherein the set of bottom cross machine direction yarns comprises eight bottom cross machine direction yarns.

18. A method of making paper, the method comprising the steps of:

(a) providing a papermaker's fabric, comprising top machine direction yarns, top cross machine direction yarns, bottom machine direction yarns, bottom cross machine direction yarns and stitching yarns, the fabric being formed in a plurality of repeating units, each of the repeating units comprising:

a set of top machine direction yarns;

a set of top cross machine direction yarns interwoven-with the set of top machine direction yarns to form a top fabric layer;

a set of four bottom machine direction yarns;

a set of bottom cross machine direction yarns interwoven with the set of bottom machine direction yarns to form a bottom fabric layer; and

a set of stitching yarns interwoven with the top and bottom fabric layers;

wherein the bottom machine direction yarns and the bottom cross machine direction yarns are interwoven in a series of repeat units in which each of the bottom machine direction yarns passes below two nonadjacent bottom cross machine direction yarns to form bottom machine direction knuckles, each bottom machine direction knuckle being separated from one adjacent knuckle by two bottom cross machine direction yarns and separated from another adjacent knuckle formed by that bottom machine direction yarn by four bottom cross machine direction yarns;

(b) applying paper stock to the papermaker's fabric; and

(c) removing moisture from the paper stock.

19. The method defined in claim 18, wherein each of the stitching yarns forms a binding knuckle with one of the bottom machine direction yarns between adjacent bottom machine direction knuckles.

20. The method defined in claim 19, wherein each of the binding knuckles is located between the two cross machine direction yarns separating two adjacent bottom machine direction knuckles.

21. The method defined in claim 19, wherein each of the binding knuckles is located between a second and third of the four bottom cross machine direction yarns separating two adjacent bottom machine direction knuckles.

22. The method defined in claim 18, wherein each of the bottom machine direction yarns is offset from adjacent bottom machine direction yarns by two cross machine direction yarns.

23. The method defined in claim 18, wherein the set of stitching yarns comprises one stitching yarn between pairs of adjacent top cross machine direction yarns.

24. The method defined in claim 18, wherein the set of stitching yarns comprises pairs of first and second stitching yarns positioned between pairs of adjacent top cross machine direction yarns.

25. The method defined in claim 24, wherein the first and second stitching yarns of each pair are interwoven with the top and bottom machine direction yarns such that, as a fiber support portion of the first stitching yarn is interweaving with the top machine direction yarns, a binding portion of the second stitching yarn is positioned below the top machine direction yarns, and such that as a fiber support portion of the second stitching yarn is interweaving with the top machine direction yarns, a binding portion of the first stitching yarn is positioned below the top machine direction yarns, and such that the first and second stitching yarns cross each other as they pass below a transitional top machine direction yarns, and such that each of the binding portions of the first and second stitching yarns passes below at least one of the bottom machine direction yarns.

26. The method defined in claim 25, wherein between 25 and 50 percent of adjacent pairs of first and second stitching yarns are interwoven as reversed picks.

27. The method defined in claim 18, wherein the set of top machine direction yarns comprises eight top machine direction yarns.

28. The method defined in claim 18, wherein the set of bottom cross machine direction yarns comprises eight bottom cross machine direction yarns.

29. A papermaker's fabric, comprising top machine direction yarns, top cross machine direction yarns, bottom machine direction yarns, bottom cross machine direction yarns and stitching yarns, the fabric being formed in a plurality of repeating units, each of the repeating units comprising:

a set of top machine direction yarns;

a set of top cross machine direction yarns interwoven with the set of top machine direction yarns to form a top fabric layer;

a set of eight bottom machine direction yarns;

a set of bottom cross machine direction yarns interwoven with the set of bottom machine direction yarns to form a bottom fabric layer; and

a set of stitching yarns interwoven with the top and bottom fabric layers;

wherein the bottom machine direction yarns and the bottom cross machine direction yarns are interwoven in a series of repeat units in which each of the bottom machine direction yarns passes below two nonadjacent bottom cross machine direction yarns to form bottom machine direction knuckles, each bottom machine direction knuckle being separated from one adjacent knuckle formed by that bottom machine direction yarn by two bottom cross machine direction yarns and separated from another adjacent knuckle by four bottom cross machine direction yarns.

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